DERIVING FOREST HARVESTING MACHINE PRODUCTIVITY FROM POSITIONAL DATA

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ABSTRACT

Automated production study systems will provide researchers a valuable tool for developing cost and impact models of forest operations under a wide range of conditions, making the development of true planning tools for tailoring logging systems to a particular site a reality. An automated time study system for skidders was developed, and in this study application of the system was compared to clock measurements on two skidders. Results showed that the system worked well in both gross and elemental time study, but that there were unexplained differences in some time elements, especially grappling times. Application of the system was somewhat complicated, and required knowledge of the site that could not be obtained before logging began, making the automated system more useful as a post-processing, rather than a real-time, monitoring tool.

INTRODUCTION

Forest practices are becoming much more information intensive, especially with regard to spatial data. GIS and GPS have become essential tools for analyzing costs, impacts, and off-site effects of silvicultural operations and their use will increase as the technology matures. Use of information technology in forest operations, however, has lagged behind its use in land management. This trend is changing as more concerns are being expressed about controlling costs and impacts of operating machinery in the woods.

A new trend toward 'precision' forestry is emerging, similar to that in agriculture where spatial technology allows management to be brought down to microsite levels. In farming, sub-field management results in greater control over application of expensive herbicides and fertilizer, and provides detailed records of the benefits derived from specific practices. The same benefits can be realized in forestry: management at a sub-stand level will result in opportunities to incorporate more detailed planning into operations, perhaps reducing costs and off-site impacts, and also provide feedback on the benefits of operations for future planning.

Time study of forestry equipment is an area where the application of spatial technology could have great benefit in advancing the development of precision forestry. Costs are always a concern in forest operations and time study is a fundamental tool in defining them. Many factors impacting costs of operations are poorly understood, mainly because long-term field research needed to evaluate their influence is impractical. A system for continuous, unattended time study of forest operations would enhance our understanding of site and machinery system factors influencing variations in costs, as well as provide a means of gaining real-time information for future planning of forest operations.

Previous work demonstrated the feasibility of using positional information to define machine function in forest harvesting operations (McDonald 1999). Positional information is easily obtained from GPS, and requires no modification of equipment to install, making it an ideal research tool for unattended time study on many logging jobs. The goal of this research was to use a GPS-based system to collect positional data during skidding operations in a tree-length logging system, use the positional data to calculate time study information, and to compare the position-based time study to field time study data.

EXPERIMENTAL METHODS

Time study data were collected over two days on two different skidders: one operated in a tree-length system (Timberjack 460C), and one in a clean chipping system (Timberjack 660). A Trimble model AgGPS 132 positioning system was installed in each. The GPS sampled and recorded positions every 2 seconds, and used a commercial satellite differential service for real time corrections (OmniSTAR). System configuration parameters are shown in table 1.

Time study was carried out on both systems using a 2-person crew, with one stationed at the deck and one positioned near the bundles. Elements were timed using synchronized stop watches with 1/1000'th minute resolution. Cycle components tracked included travel empty, grappling and positioning, and travel loaded. One operator (460C) delimbed every load using a gate, but this element was not tracked separately and was included in travel loaded times. The other operator delimbed only occasionally, normally using standing dead or unmerchantable timber as an impromptu gate, and the element was not broken out in that case either. Total cycle time data were collected on 48 skid cycles, elemental times on 37 of those. Skid distances were measured on a sub-set of the cycles (total of 27). On one site, distances were measured using a laser rangefinder, and on the other a distance wheel was used.

GPS data were reduced using the analysis system described in McDonald (1999). The reduction system used a 2-phase process that began with a site specific, machine independent identification of movement-defined events, and, in the second phase, combined series of movement events into elemental times. For example, a travel loaded skidder element would be recognized by the movement events of a skidder first leaving the deck, then traveling away from the deck, and at some point stopping and reversing direction to back up to the bundle of trees.

The first, or site specific, analysis phase involved defining a set of physical features that were important 'landmarks' on the sites, then filtering the raw positional data through a program which output a series of 'events' describing the motion of the skidder. The process is illustrated using the data in Figure 1. The figure shows a map of skidder motions in a typical skid cycle as collected using the GPS. Also included in the map were a set of lines and polygons that were the landmarks defined in the analysis of data at this site. Landmarks were drawn in by hand and, once defined, the first phase of the analysis was to evaluate the

Table 1. Settings used for key GPS parameters.

Parameter	Setting
Mode	Manual 3D
AMU (SNR) Mask	6
Elevation Mask	15°
PDOP Mask	6
PV Filter	Off
Dynamic Mode	Land
DGPS Mode	Auto On-Off

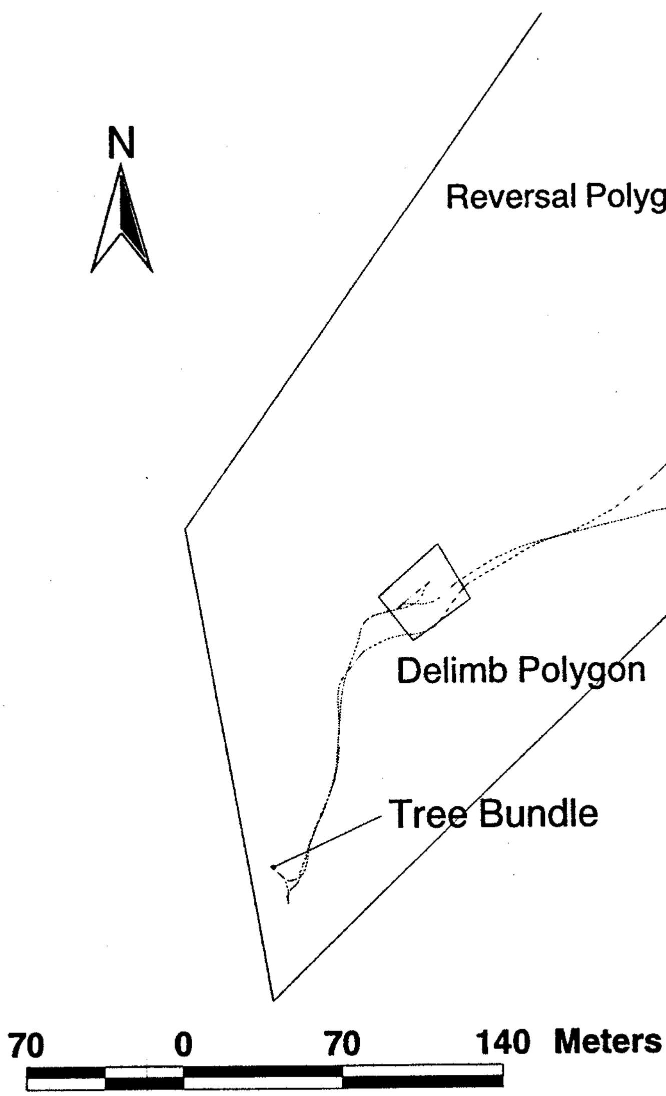

Figure 1. Path for a skidder operating in a clean chipping system. Data were sampled at 0.5 Hz using a Trimble AgGPS 132.

interaction of the skidder with the landmarks. For example, instances of the skidder reversing direction, crossing a designated line, or occupying a polygon were located. The events resulting from the first phase of the analysis of this cycle are shown in listing 1.

The second phase of the analysis parsed streams of events (as in listing 1) using a set of rules to convert them into meaningful elements. The rules were specified using a modified regular expression syntax. Rule definitions expressed compound events in terms of simpler events, and when a rule was matched the time and distance parameters of each of the rules' components were accumulated and 'reduced' to the rule name (left of the ':'). The ruleset used in this study is shown in listing 2.

RESULTS AND DISCUSSION

Gross Time Study

There was a total of 48 skid cycles timed using GPS and field crew measurements. Of that total, 3 cycles (6 percent) were not identified from GPS analysis: one because of a failure in the cycle parsing system, and two because of a loss in GPS signal. Correspondence of total cycle time from GPS and clock measurements in the remaining 45 cycles was very good, the difference averaging less than 3.5 percent (@sigma@ = 11 s). There was a statistically significant difference ($P < 0.001$) in the total cycle time errors between the two measurement sites. For the Timberjack 460 skidder, total cycle time errors averaged 2.3 percent (@sigma@ = 9.4 s) while for the Timberjack 660 the error averaged 4.5 percent (@sigma@ = 13 s) The difference was probably due to the landmarks (in this case, the deck boundary) used in deriving GPS cycle time not corresponding to those used in the clock time study, and illustrated the sensitivity of the GPS measurements to placement of landmarks. These differences might have been eliminated had the deck boundary been established using GPS, rather than drawing it in based on a map of the site.

The one cycle not identified using the cycle parsing system was a result of the operator stopping to talk with a crew member. The location the skidder stopped happened to be inside the area designated as the delimbing zone in the site mapping phase of the analysis, resulting in a delimbing event being identified at the beginning of the cycle. Such uncharacteristic cycles can be reduced, but it would require writing a special case parsing rule to handle the situation.

GPS-estimated skid distances differed significantly from those measured on the ground ($P < 0.005$). On average, the GPS estimate was 12 percent greater (49 m, @sigma@ = 53 m, N = 27) than direct observation. This was as expected since ground measurements do not typically account for movement during delimbing, and in this case grappling the load. GPS-derived travel empty + travel loaded distances (removed travel associated with grappling load and delimbing) were, therefore, compared with total ground-measured skid distances. In that case, the GPS-derived distances were 0.4 percent greater, on average, than ground measurements, again probably due to differences in landmark locations, and also to some minor flaws in the calculations of the cycle parsing system (rounding errors and ignoring of some distance elements). This difference, however, was not statistically significant.

An experiment was conducted to test distance measurements under more controlled conditions. Three courses were laid out resembling a skid cycle, with a 'deck', and a simulated load and delimbing gate. Distances along the course were measured with a road wheel, ranging from 330 m to 603 m in total length. A car was then fitted with the GPS system and driven over the three courses, three times each. The data were reduced using the same approach as in deriving time study data from skidders, and distances measured via GPS compared with those from the wheel. In 8 of the 9 cases, the GPS measurement of total cycle distance was longer. The average difference was 1.5 percent (7.3 m, @sigma@ = 8 m), and signficantly different from 0 ($P < 0.04$). Although non-zero, the differences were small and considered acceptable over a range of total cycle distance from 300 to 600 m.

Elemental Time Study

Elemental time study data were available for a total of 37 skidder cycles. Elements measured included travel empty, grappling, and travel loaded. Of the 37 cycles, the parsing rules reduced to elemental times in all but 3 cases. One instance was mentioned above (pausing to talk inside the delimbing area), while the other two resulted from similar circumstances. In one case, there was only one reversal of direction noted during the grappling phase, essentially folding the grappling time into travel loaded. In the second, there was a bundle of trees located in the delimbing area and no cycle was detected. In each of these failures, a rule (or rules) to handle the unusual circumstances could have been added and the cycles reduced, but this was felt to violate the premise that a general set of rules could be developed that would be effective in unsupervised time study analysis.

The most consistent correspondence between measured elemental times and GPS-derived times was that of the travel empty component. On average, the difference between GPS and clock measurements of travel empty was 4.7 percent (4.6 s, @sigma@ = 1.7 percent). Clock times were longer, and the difference was significantly greater than 0 ($P < 0.03$). GPS grappling times were 21 percent greater, on average, than clock values (10 s, @sigma@ = 11 percent). The difference, however, was highly variable and not significantly different from 0 ($P = 0.07$). GPS travel loaded times averaged 3 percent greater than clock times (6 s, @sigma@ = 3 percent), and were not significantly different from 0 ($P = 0.05$).

Delimbing time was not measured as part of the clock time study, but delimbing did occur and it was detectable from the cycle parsing system. Delimbing was recognized in all cycles in which it was performed (total of 20), but required intervention on the part of the user. Both grappling and delimbing were detected based on reversals in direction of travel, but distinguishing one reversal from the other required some contextual knowledge. This generally meant that the two actions were physically separated in space. Since delimbing mainly happened in a particular spot, distinguishing the two events was possible by defining a polygon around the delimbing zone and looking for those reversals inside and outside that polygon. This approach worked very well, but required some site specific information that may not have been available in a stand-alone situation.

Discussion

In general, the cycle parsing system worked very well in evaluating time performance of skidders. Defining the parser rule set to perform the cycle reduction was complicated, but, once established, the system was robust and capable of recognizing most operational events. Performance in gross time study was quite good, with better than 90 percent recognition rate. Correspondence with clock time study was also good, although there were biases apparent in some cases that were probably caused by different defintions of cycle starting and ending points between the clock and GPS analyses.

Elemental time study was also possible with the system, although correspondence with clock times was less precise. Travel empty and travel loaded times were close to clock values, but grappling times were subject to some large errors. In about 25 percent of the cycles, grappling times differed from clock-estimated values by nearly 100 percent, normally over predicting the amount of time required to grapple the load. It was not obvious what caused the errors, but they could likely be reduced with the addition of other sensors to the system that tracked, for example, grapple status. This type of modification to the system, although feasible, would require additional equipment to be installed on the skidder, increasing setup time and the likelihood of breaking system components.

Although grapple times were the least accurate elemental component from the GPS-based time study, they were the most interesting. Travel empty and travel loaded times were fairly consistent throughout most of the experiment, but grapple times varied quite a bit, in most cases representing about 10 to 15 percent of the total cycle time, but in a few cases the portion increased to nearly half. There was no obvious difference in the bundles in the cases of high grappling times, but perhaps a limit in bundle size had been exceeded that could have been detected with an automated production monitoring system on the feller-buncher. Given that this type of problem happened frequently, it illustrated the potential for increasing overall productivity using continuous monitoring systems on logging equipment.

CONCLUSIONS

Previous work had shown the potential for automated time study using positional information alone. This study showed that the time study system was also acceptably accurate in most cases, particularly in evaluating gross production. Elemental time study was also possible, but required greater analysis time and was subject to larger errors when compared to clock studies.

The time study analysis system was intended to gain the maximum amount of useful information from positional data alone. To be truly effective, any automated time study system must require little or no modification to the contractor's equipment, be robust enough to withstand harsh operating conditions, flexible enough to handle many different silvilcutural prescriptions, and not require any interaction with the machine operator. The developed system meets these criteria and should be applicable for continuous automated time study in skidders, at least in a post-processing mode. Real time evaluation of production requires information (mainly the 'landmark' data) that is not known *a priori*. Overcoming this limitation will require some intervention on the part of an operator, or addition of instrumentation to detect events that would otherwise be recognized by spatial patterns. Adding additional instrumentation, however, complicates the installation of the system and potentially reduces reliability.

Achieving fully automated productivity tracking will require further development of the time study system. Reliability of the data collection components and a means of accessing them remotely will have to be addressed. The parsing system needs further verification to ensure that results are completely accurate. Finally, the system will also require a means of measuring load size to perform true production studies.

LITERATURE CITED

1. McDonald, Tim. 1999. Time study of harvesting equipment using GPS-derived positional data. In: Forestry Engineering for Tomorrow, Proceedings of the 1st International Forest Engineering Group Meeting; 1999 June 28-30; Edinburg, Scotland. Silsoe, Bedford, UK:Institution of Agricultural Engineers.

Listing 1. Events identified for the skidder path data found in figure 1. The left column is the type of event, the middle the time since the last event (in seconds), and the right column the accumulated travel distance since the previous event (m).

```
leave_deck      28      54.90371977
x_t     10      30.4780185
rev_grapple     152     395.5406015
rev_grapple     10      13.03729044
rev_grapple     4       0.1610806012
rev_grapple     2       0.0736958244
rev_grapple     6       0.5002278212
stop_grapple    2       0.08453413608
rev_grapple     0       0
rev_grapple     4       0.05984905904
rev_grapple     2       0.1073615665
rev_grapple     4       0.5336364186
rev_grapple     4       0.156648024
rev_grapple     2       0.1100009504
rev_grapple     6       0.6034057332
rev_grapple     2       0.1094566653
rev_grapple     2       0.1920085918
start_grapple   4       2.295245245
rev_grapple     0       0
rev_delimb      82      163.8705463
rev_delimb      16      19.35506391
x_t     100     247.7917976
enter_deck      18      40.10089877
```

Listing 2. Parser rule set used to reduce event data into skidder time study elements.

```
travel_empty: leave_deck^ {x_t }+rev_grapple ;

grApple: travel_empty^ {{rev_grapple }{start_grapple }{stop_grapple }} ;
grApple: grApple {{rev_grapple }{start_grapple }{stop_grapple }}+ ;

int_travel: grApple^ rev_delimb ;
delImb: int_travel^ {{rev_delimb }{rev_grapple }}*x_t$ ;

travel_loaded: grApple^ {x_t }+enter_deck ;
travel_loaded: delImb^ {x_t }+enter_deck ;
```